

Current-sense amplifier handles high voltages

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High-side current-sense amplifiers, such as IC₁ in Figure 1, monitor current from a battery or dc power line in systems for which the ground-return continuity is crucial. IC₁'s 36V maximum operating voltage, however, excludes some applications, including traction-motor batteries and central-exchange power supplies, both of which require operation at voltages exceeding 72V. The external circuitry in Figure 1 allows IC₁ to monitor current at voltages of 300V and greater. Q₁ and Q₂ form a current source whose compliance voltage provides the high-voltage capability. IC₁ draws its 100- μ A supply current from a simple floating power supply comprising C₁, C₂, avalanche diode D₁, and the Q₁-Q₂ current source.

Voltage applied to R₁ biases the current source and provides a ground-referenced means of shutting off the circuit. The current value (1 mA in this case) ensures regulation in D₁. Q₁ should have a maximum compliance of 300V, yielding 305.1V for the maximum V_{IN}. Substituting a 33V avalanche diode for D₁ boosts this maximum to 333V. IC₁'s output terminal provides a current source with a typical 3-M Ω output impedance, which generates 500 μ A per ampere

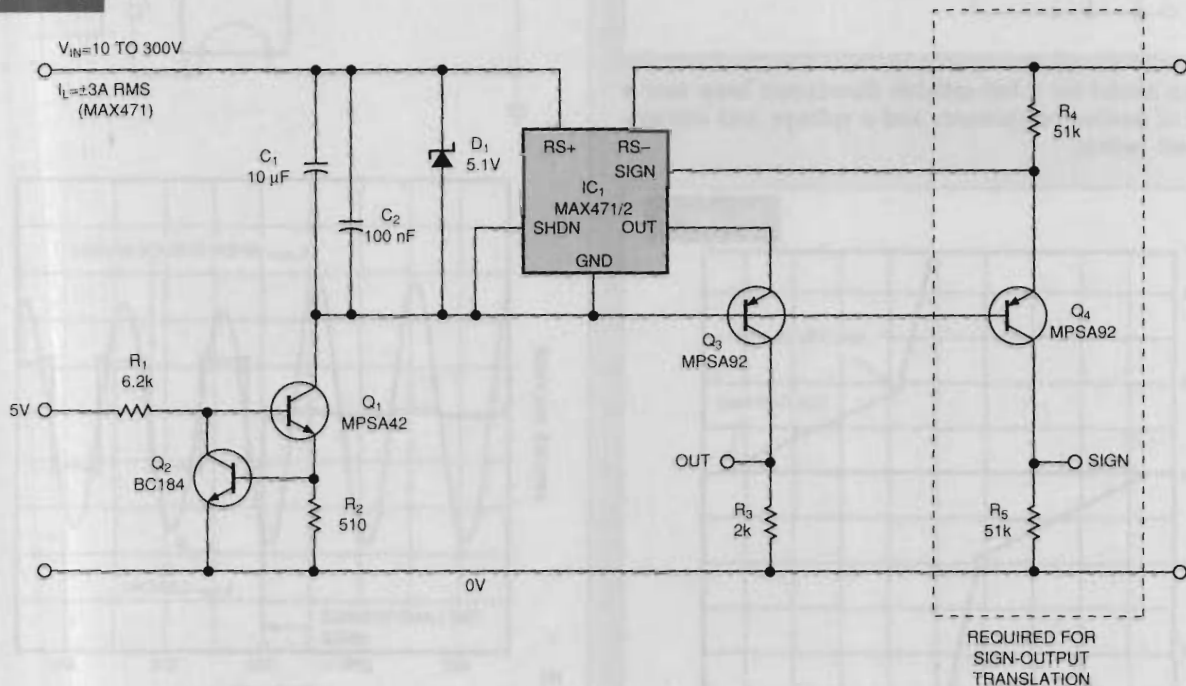
of current flowing through the sense terminals, RS+ and RS-. The high-voltage, pnp common-base stage Q₃ routes the output current to R₃. Q₃ is the complement to the high-voltage npn transistor, Q₄.

The result is a ground-referenced signal that is proportional to the monitored current. You select R₃ to provide the desired full-scale output voltage. The only error in the output signal comes from the current-gain factor, α , for a common-base stage: $\alpha = \beta / (1 + \beta)$, where β is the transistor's dc gain. Q₁'s minimum β is 25, yielding a minimum α of 0.96. To bring the α closer to unity, increase the current gain by replacing Q₃ with a Darlington device. With the values in Figure 1, Q₃'s collector voltage changes less than 10 mV over the 10 to 300V V_{IN} range. A similar common-base stage, Q₄, translates IC₁'s polarity output, which indicates the direction of current flow through the sense terminals, to provide a ground-referenced logic-level Sign output. (DI #2109)

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FIGURE 1



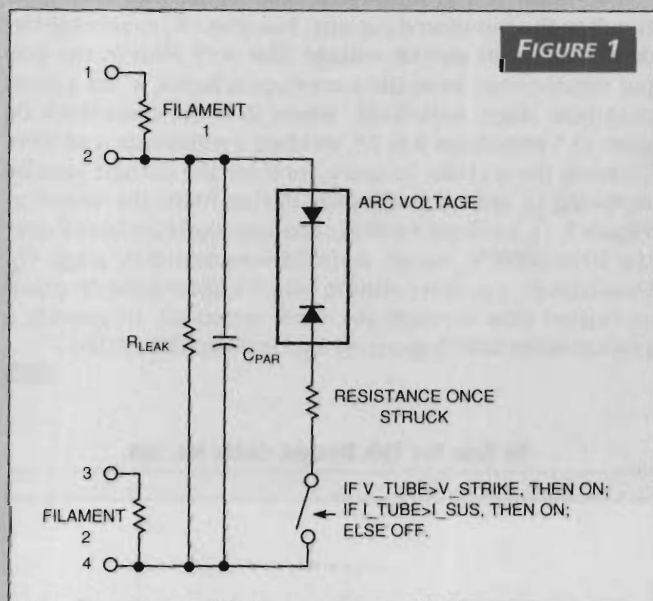
A few external passive components and high-voltage transistors multiply a current-sensing IC's operating voltage almost ten-fold.

Spice simulates a fluorescent lamp

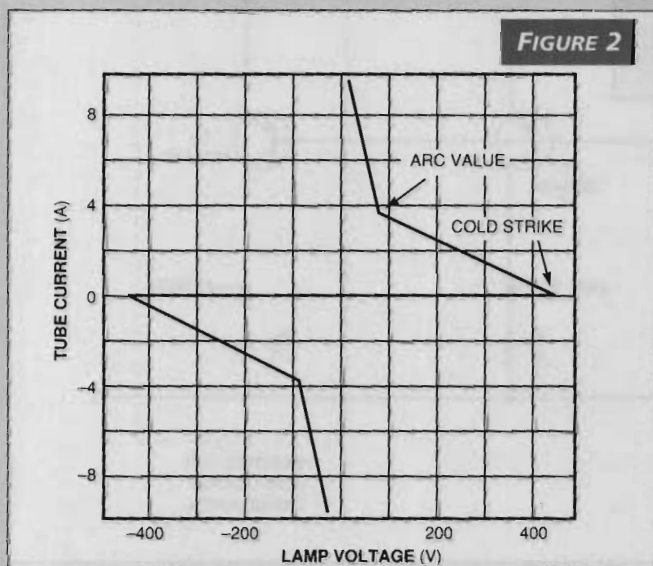
CHRISTOPHE BASSO, PIBRAC, FRANCE

A hot-cathode fluorescent lamp (HCFL) contains a gaseous mixture that flows between two tungsten electrodes, or filaments. In domestic applications, the mixture comprises

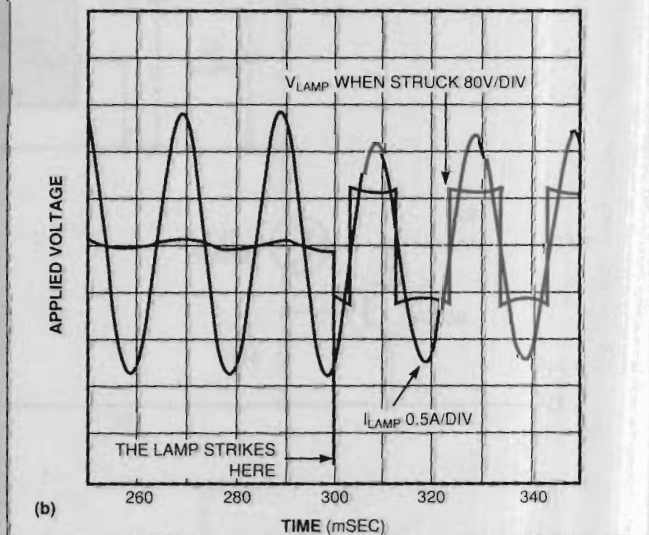
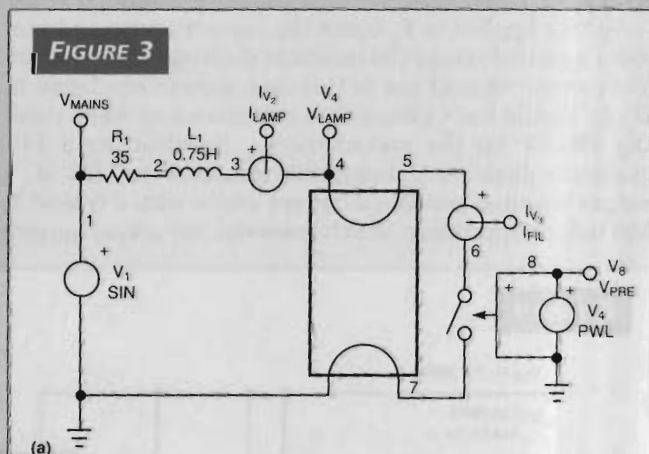
mercury vapor and a small quantity of inert gas (krypton or argon). The inert gas vaporizes the mercury during turn-on. To lengthen the filament's lifetime, a preheating period brings the electrodes to a high-enough temperature before avalanche occurs. The warm-up is easy to effect by supplying the filaments with ac or dc during the first few hundred milliseconds. During this emissive period, the filaments increase the electron population in the tube and consequently reduce the avalanche potential, thereby resulting in a lower striking voltage for the lamp. Once struck, the lamp maintains a quasiconstant voltage, or "arc voltage," across



The Spice model for a hot-cathode fluorescent lamp uses a handful of passive components and a voltage- and current-dependent switch.



The I-V characteristic of a hot-cathode fluorescent lamp clearly shows the lamp's negative-resistance nature.



This test circuit (a) uses Spice to simulate a fluorescent lamp in a typical 50-Hz application. The simulation results appear in (b).

its terminals. A practical value for the cold-striking voltage for a 5-ft lamp is approximately 1 kV, with a corresponding arc voltage of approximately 110V rms. A Spice technique offers an easy way to model an HCFL (Listing 1). You can download the listing from EDN's Web site, www.ednmag.com. At the registered-user area, go into the Software Center to download the file from DI-SIG, #2108.

You can operate an HCFL at low or high frequency. At low frequency—for example, in a 50- or 60-Hz ballast application—the conducting gas reacts faster than the ac line. Every time the line polarity changes, the lamp current cancels, and the tube halts its conduction. The lamp then must restrike with the opposite polarity but at a voltage lower than its cold value because of the lamp's temperature. At this low operating rate, the voltage across the tube decreases as the current increases because of the negative-impedance characteristic of the conducting gas. At frequencies above a few kilohertz, these effects smooth out, and you can represent the tube using a resistive and weak capacitive filter.

You can model a fluorescent tube in several ways (Reference 1). Fitting the current-voltage characteristic represents an elegant option, but the parameter extraction from the manufacturer's data-sheet curves is complicated. Instead, the Spice macro-modeling technique offers a simplified and efficient method for generating the model. The technique uses Spice primitives to describe the lamp's complex electronic function.

The generalized model of the lamp is easy to understand (Figure 1). If the voltage on the tube is lower than the cold-strike voltage, no current flows except in the leakage elements. If the voltage increases and attains the striking voltage, the voltage-controlled switch closes, and the back-to-back zener network connects across the tube's terminals. The voltage then collapses to the arc value, and a current flows in the tube. The tube stays conductive until the current falls below the sustaining value. At this point, the switch opens, and the tube needs restriking. The netlist applies to IntuSoft's (San Pedro, CA) IsSpice4 simulator and uses standard Spice 3 elements with one of IntuSoft's Spice extensions, an if-then-else

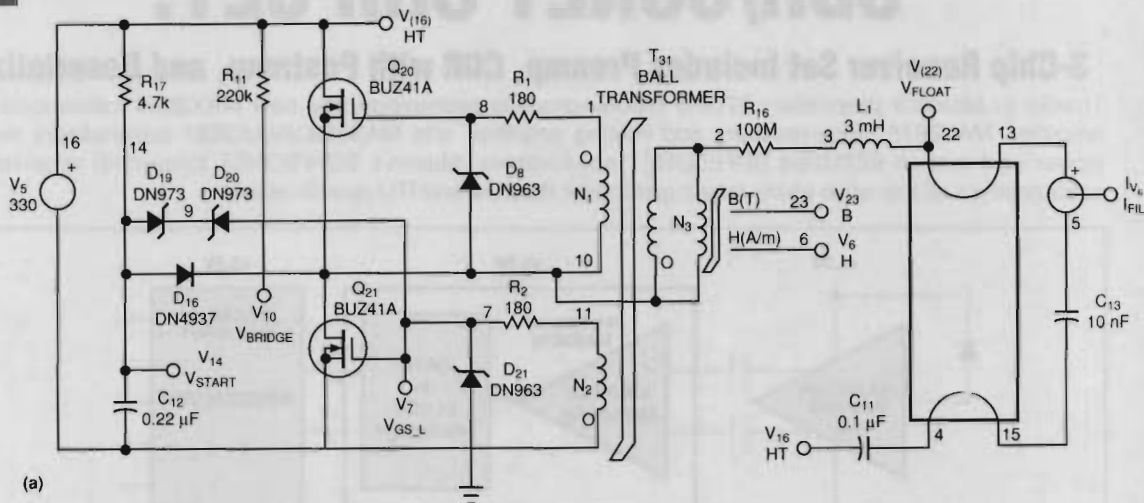
LISTING 1—SPICE MODEL FOR FLUORESCENT TUBE

```
*
* FLUORESCENT TUBE MODEL DEVELOPED BY CHRISTOPHE BASSO (FRANCE)
*
* VTHRES = COLD VOLTAGE AT WHICH THE LAMP STRIKES
* THIS VALUE DIMINISHES IF CURRENT FIRST FLOWS VIA FILAMENTS
* VARC = VOLTAGE CORRESPONDING TO THE LAMP ARC VOLTAGE
* ISUS = CURRENT UNDER WHICH THE ARC IS STOPPED
*
.SUBCKT TUBE 1 2 3 4 [VTHRES=250 VARC=50 ISUS=100M]
    F1 F1 F2 F2
RDUM1 2 4 100MEG
VDUM 1 10 ; Lamp current measurement
RFIL1 1 20 2.5 ; Filament resistance 1
VFIL 20 2 ; Filament current measurement
RFIL2 3 4 2.5 ; Filament resistance 2
CPAR 1 3 1P ; Open-lamp capacitance
RLEAK 1 3 10MEG ; Open-lamp leakage current
RNEG 10 11 -10 ; Negative behavior once struck
DSTK1 12 11 DCLAMP ; Lamp voltage once struck, polar +
DSTK2 12 16 DCLAMP ; Lamp voltage once struck, polar -
* RSTK 10 16 16S ; For pure resistive behavior in AC over a few kHz (58W)
CARC 1 16 100P ; Arc capacitance
X1 16 3 13 SWITCH
BARC 15 0 V=ABS(V(1,3))>[VTHRES] ? 100V : ABS(I(VDUM))>[ISUS] ? 100V : ABS(V(1,3))>V(14) ?
+ 100V : V(19)>3V ? 100V : 10N
RDEL 15 13 100 ; Adjust the turn-on time
CDEL 13 0 100P
**** OPERATING VOLTAGE ONCE STRUCK ****
CDIF 13 17 1N
RDIF 17 0 10K
BDIF 18 0 V=V(17)>10 ? 100 : ABS(I(VDUM))>[ISUS] ? 100 : 0
RINT1 18 19 50K
CINT1 19 0 3NF
**** FINDING THE FILAMENTS RMS CURRENT ****
BI2V 0 25 I=ABS(I(VFIL)) ; Filament current
RI2V 0 25 1 ; Convert to Volts
DCR 25 26 DSCR
CCR 26 0 1NF ; Peak detection
RDUM3 26 0 100MEG
BSQR 27 0 V=V(26)/1.414 ; RMS value for sinus only
RSQR 27 0 1
**** PREHEATING SECTION FOR DC AND AC ****
BPRE 14 0 I=V(14)>[VTHRES/2] ? -(BSQR)*3 : 0
CPRE 14 0 2MF IC=[VTHRES]
RDUM2 14 0 100MEG
.MODEL DCLAMP D BV=[VARC]
.MODEL DDIS D RS=10
.MODEL DSCR D N=0.1
.ENDS
*****
.SUBCKT SWITCH 1 2 3
R1 1 2 1E10
G1 1 2 POLY(2) 1 2 3 0 0 0 0 1
.ENDS
```

behavioral element.

Preheating the filaments reduces the striking voltage. The model accounts for this behavior and monitors the current flowing through the filaments before the first cold strike. To take advantage of this modeling feature, you should include the UIC (use-initial-conditions) key word in the transient Spice statement. In ac applications in which the period of operation is short, the thermal effects ensure a restrike voltage close to the arc value. This close conformance is especially true for high-frequency systems, such as electronic ballasts. The Spice BDIF element simply models this effect.

FIGURE 4

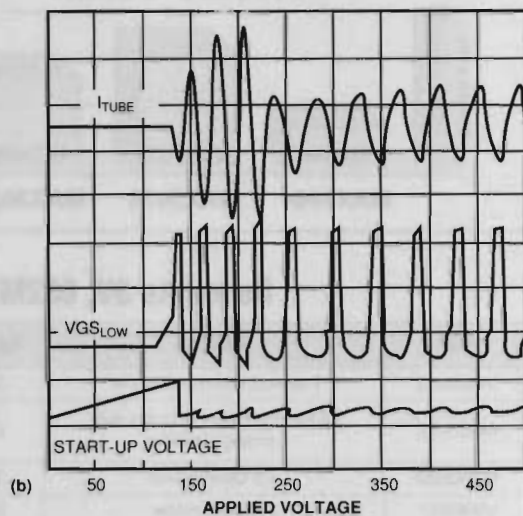


A self-oscillating ballast (a) using a saturable current transformer with a nonlinear magnetic core drives the fluorescent tube. IsSpice4 yields the simulation results (b) for the self-oscillating ballast configuration.

Figure 2 shows the current-voltage characteristic of the IsSpice4 model; you can clearly see the negative-resistance effects.

Figure 3a shows a low-frequency test circuit using the tube model in a classic 50-Hz application; Figure 3b shows the simulation results. To operate the tube model at higher frequencies, simply remove the * before the RSTK element in the netlist and place one before the RNEG, DSTK1, and DSTK2 elements. Figure 4a shows a typical application for a self-oscillating ballast. You can calculate RSTK from the lamp's rms operating characteristics: $RSTK = V_{ARC} / I_{NOM}$. For a 36W tube, $RSTK = 103 / 0.43 = 240\Omega$.

In Figure 4a, a saturable current transformer drives two MOSFETs. The transformer uses IntuSoft's nonlinear magnetic-core model. R_{17} and C_{12} drive the start-up, forcing Q_{21} to start conducting a few milliseconds after applying the mains. Square waves then appear on the undamped L_1 - C_{13} network, and a high voltage appears across the tube ends. C_{13} also ensures preheating of the filaments. Once the tube strikes, the resulting load changes the operating frequency of the ballast. Figure 4b shows the IsSpice4 simulation results. The model runs fast and converges without difficulties in low- and high-frequency applications. Thanks to its macro-modeling structure, the model's operating param-



eters easily adapt to various lamp types. Reference 2 gives further insight into self-oscillating-ballast techniques. (DI #2108)

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References

1. Vladimirescu, Andrei, *The Spice Book*, John Wiley and Sons, ISBN 0-471-60926-9.
2. "Energy-efficient semiconductors for lighting," Application Note BR480/D, Motorola Semiconductor, Austin, TX.

ST-bus channel locator eases debugging

YS TAM, CANADIAN MARCONI CO, OTTAWA, ON, CANADA

A simple circuit (Figure 1) can locate one of 32 channels in the serial stream of an ST-bus, which is helpful for both debugging and monitoring. The ST-bus comprises a framing signal for frame alignment, a clock signal for bit timing, and a serial information stream for data transmission. The clock rate is 2.048 Mbps, the frame signal is 8 kHz, and the serial information stream contains 32 channels with 8 bits per channel.

The setting of the 5-bit switch determines the selected channel. The chan_loc signal goes high to indicate the beginning of the selected channel and stays high for the whole period of the channel. The channel counter, chan_cnt in Listing 1, is always one channel ahead of the channel slot. Listing 1 is the VHDL source code for the EPM5032 (Altera Corp, San Jose, CA). You can download the listing from EDN's Web site, www.ednmag.com. At the registered-user area, go into the Software Center to download the file from DI-SIG, #2098. (DI #2098)

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LISTING 1—CHANNEL COUNTER

```
--
-- ST-BUS Time-slot Locator
-- Device: EPM5032
--
ENTITY slotpag IS
    PORT
    (
        clk2m      : IN  BIT; -- clock
        sync       : IN  BIT; -- frame sync
        chan_num   : IN  integer range 0 to 31; --select channel input
        chan_loc   : OUT bit  -- selected channel indicator
    );
END slotpag;

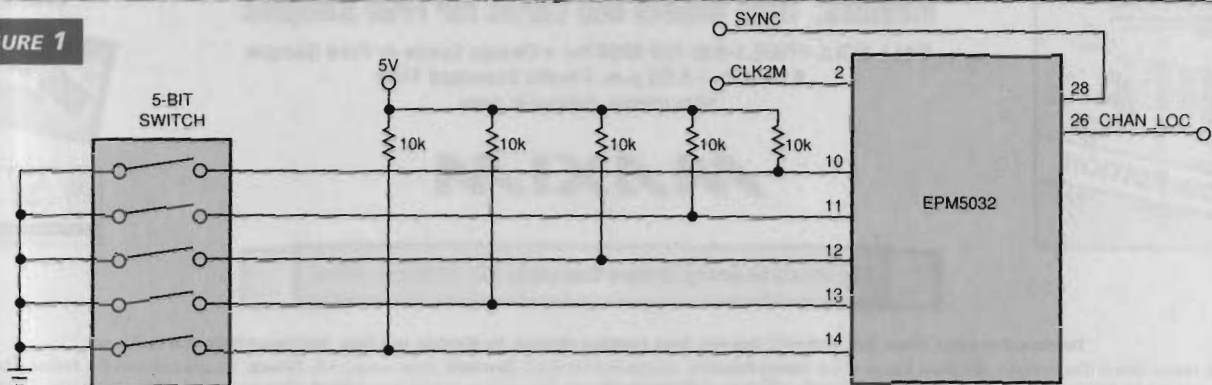
ARCHITECTURE arch OF slotpag IS
    BEGIN
        PROCESS (clk2m)
            VARIABLE bit_cnt : INTEGER RANGE 0 TO 7; -- bit counter
            Variable chan_cnt : INTEGER range 0 to 31;-- channel counter
            variable ind      : bit;
        BEGIN
            IF (clk2m'EVENT AND clk2m = '1') THEN
                IF (bit_cnt = 7) THEN
                    IF (chan_cnt = chan_num) THEN
                        ind := '1';
                    ELSE
                        ind := '0';
                    END IF;
                ELSE
                    END IF;

                IF sync = '1' THEN
                    IF (bit_cnt = 7) THEN
                        chan_cnt := chan_cnt + 1;
                        bit_cnt := bit_cnt + 1;
                    ELSE
                        bit_cnt := bit_cnt + 1;
                    END IF;
                ELSE
                    bit_cnt := 0;
                    chan_cnt := 1;
                END IF;
            ELSE
                END IF;

            END IF;

            chan_loc <= ind;
        END PROCESS;
    END arch;
```

FIGURE 1



In this ST-bus channel locator, the chan_loc signal goes high to indicate the beginning of the selected channel.

RS-232C link monitors animal activity

W STEPHEN WOODWARD, UNIVERSITY OF NORTH CAROLINA—CHAPEL HILL

A common need in biological experimentation is the ability to unobtrusively monitor the activity of small caged animals, such as mice, rats, and rabbits, as they move about their enclosures. This monitoring must be over long periods and around the clock. The circuit in **Figure 1** allows you to effect long-term, unattended collection of animal-behavior data using any standard PC with an RS-232C port. The circuit detects changes in the proximity of the animal subjects to a capacitive sensor electrode. The multivibrator comprising IC₁₀, IC₁₁, and IC_{1F} drives the electrode with a 5V p-p, 200-kHz square wave.

Potentiometer R_2 adjusts the amplitude of the excitation, thus adjusting the overall sensitivity. Because any displacement currents sourced to the electrode must pass through the half-wave rectifier, Q_1 - D_1 , the average dc collector in Q_1 is proportional to the product of the excitation current and C_x , the sensor-electrode capacitance. Therefore, as the animals move about their cage, they alter C_x and produce corresponding variations in I_c .

The current-to-voltage converter comprising IC_{1A'}, IC_{1B'} and IC_{1C} provides I_C information to the PC. C₂ stores the integrated charge from I_C. As C₂ charges, the voltage on Pin 1 of IC₁ rises until it reaches the logic-0 to -1 threshold. The multivibrator then switches, forward-biasing D₂ and discharging C₂, and generates an approximately 400-μsec pulse. Meanwhile, the RCD (received data) signal of the RS-

232C interface goes high for an interval consistent with a valid RS-232C Start pulse. This high signal results in the port's assembling a correctly framed although meaningless character. The frequency of character transmission is proportional to the rate of charge of C_2 ; therefore, it is proportional to I_c and C_X .

With the circuit values in Figure 1, the constant of pro-

LISTING 1—MOVEMENT RELATIVE TO THE ELECTRODE

```

DIM A(15000)

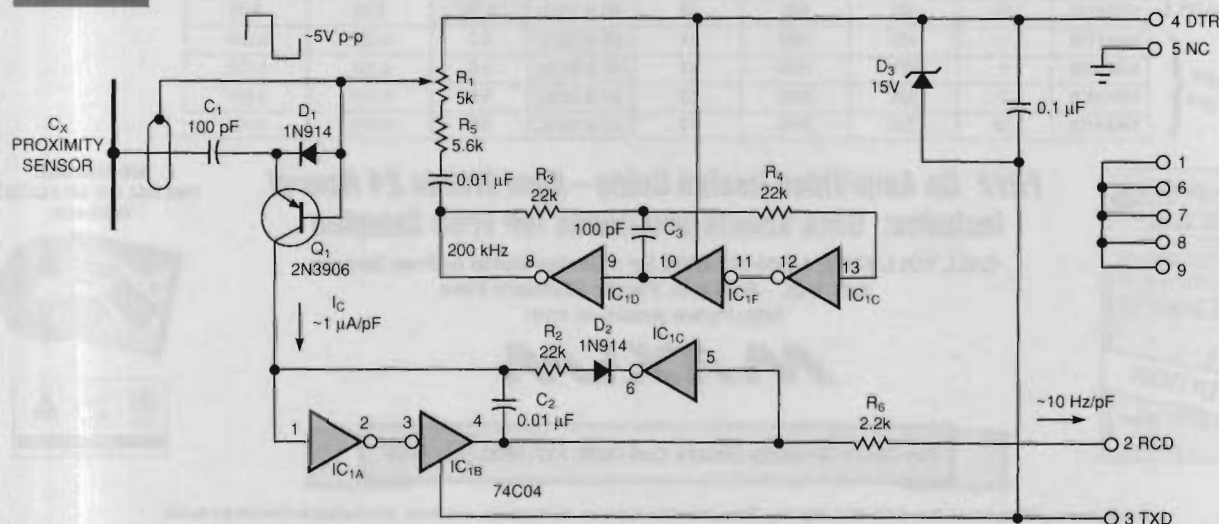
TIMECON = 241 * 3600 / 1280 : 1280 DATA IN 24HOURS
ALCO = TIMECON * TEMPCO: TINC% = TIMECON * 18.2065
SNO = 2 * TIMECON
DEF SEG = 0: ' SET UP TO WATCH TIME OF DAY CLOCK IN (&H46C,D)

SCREEN 11: PSET (0, 199), 15
OPEN "COM1:9600,N,5,1,BIN,RB5000" FOR INPUT AS #3

Y% = PEEK(&H46C)
WHILE PEEK(&H46C) = Y%: WEND: A$ = INPUT$(LOC(3), 3)
TODAY$ = DATE$: STIME$ = TIME$: PRINT TODAY$, STIME$

FOR I% = 0 TO 1280 - 1
SUM = 0: FOR Z% = 1 TO TINC%
Y% = PEEK(&H46C): WHILE PEEK(&H46C) = Y%: WEND
X% = LOC(3): SUM = SUM + X%
A$ = INPUT$(X%, 3): IF INKEY$ = "$" THEN GOTO ALLDONE
NEXT
LINE = (I% / 2.199 - SUM / SNO)
A(I%) = SUM
NEXT
ALLDONE:

```

FIGURE 1

A capacitive sensor provides unobtrusive and humane monitoring of the behavior of small animals in cages.

portionality is approximately 10 Hz/pF. By measuring character frequency, software running on the PC can detect and tally fluctuations in proximity-electrode capacitance and, therefore, animal movement relative to the electrode (Listing 1). The Basic routine provides average proximity data at a little less than one datum per minute to produce a graphing-convenient of 1280 points per day. This monitoring scheme uses no moving parts, such as mechanical sensor switches; therefore, the scheme is inexpensive and robust.

And, unlike clicking switches and photoelectric-sensor light sources, it produces no unwanted or disruptive stimulation of the subject animals. Because the circuit's power demands are low and unfussy, you can conveniently "borrow" all necessary power from the DTR (data-terminal-ready) and TXD (transmitted-data) lines of the port. (DI #2107) EDN

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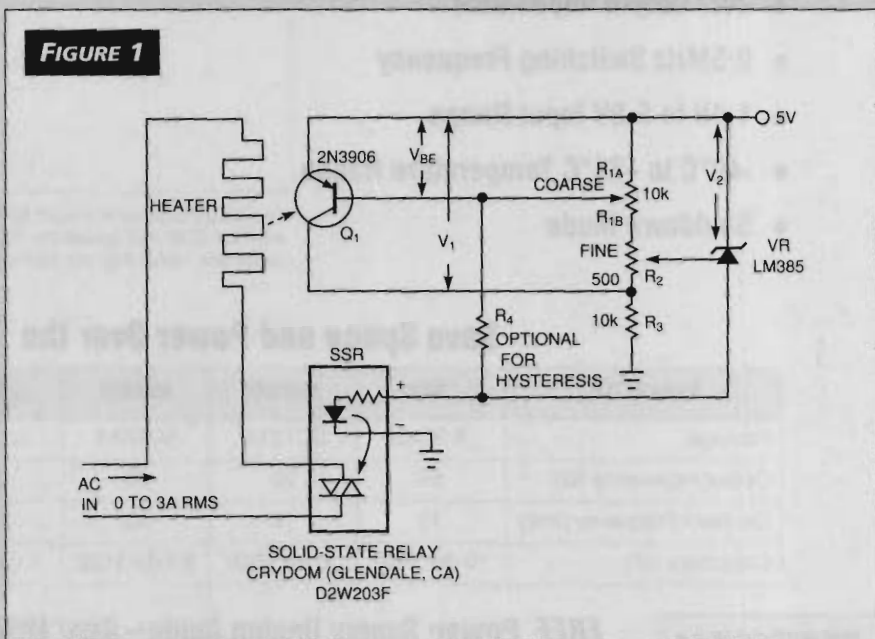
Bang-bang thermostat is simple and efficient

W STEPHEN WOODWARD, UNIVERSITY OF NORTH CAROLINA—CHAPEL HILL

Perhaps the simplest and oldest feedback loop is the nonproportional, all-or-nothing, "bang-bang" thermostat. Fully turning on a heater when the temperature is below setpoint and off when it's above setpoint is a straightforward example of a servomechanism. Yet, elementary and crude as servomechanisms are, examples surround us in virtually every household-room thermostat, clothes dryer, oven, and aquarium heater, to name a few. The version in Figure 1 preserves the best features of the old bang-bang: low cost, simplicity, and efficiency combined with setpoint stability.

Q_1 serves as a temperature sensor via the $-2\text{ mV}/^\circ\text{C}$ temperature dependence of its V_{BE} . In combination with R_1 and R_2 , Q_1 forms a standard V_{BE} multiplier. Q_1 's collector-emitter voltage, V_1 , equals $V_{BE}(R_1+R_2)/R_{1A}$, where R_{1A} is the part of R_1 's resistance element between the 5V supply and the wiper. Thus, by adjusting R_{1A} over the range 0 to R_1 at any chosen Q_1 temperature, you can set V_1 virtually anywhere at V_{BE} to 5V.

Because the R_1 adjustment covers such a wide range, it is almost impossible to set a precise temperature using R_1 by itself. You thus need R_2 to fine-tune V_2 , the voltage at the adjust terminal of VR, over the range 0.95 to 1.0 times V_1 . By properly adjusting R_1 and R_2 , you can set V_2 to equal 1.24V, the internal bandgap-reference voltage of the LM385 shunt-regulator chip VR, when Q_1 is at the desired setpoint temperature. Once you establish this setting, VR conducts (thereby turning on the optically isolated solid-state relay, SSR, and applying power to the heater) whenever V_2 rises above 1.24V, as it does if Q_1 cools below setpoint temperature.



A classic example of a bang-bang thermostat, this low-cost circuit exhibits good setpoint stability and fine-resolution temperature adjustment.

When Q_1 warms back up to setpoint, however, V_2 falls below 1.24V and VR ceases conduction, turning off SSR and the heater. You can add hysteresis, which is sometimes useful if too-frequent cycling of the heater is undesirable, by using R_4 according to the formula $T_H = 4.4 \text{ M}\Omega/R_4$, where T_H is the temperature hysteresis. For 2°C hysteresis, for example, R_4 equates to $2.7 \text{ M}\Omega$. Setpoint stability is excellent if you use good trimmers for R_1 and R_2 . In practice, the dominant cause of any temperature variation is likely to be drift in the 5V supply. The setpoint has approximately $0.2^\circ\text{C}/\%$ dependence on supply drift. (DI #2113) EDN

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(continued on pg 114)